Blowing Up Pbar Emittances

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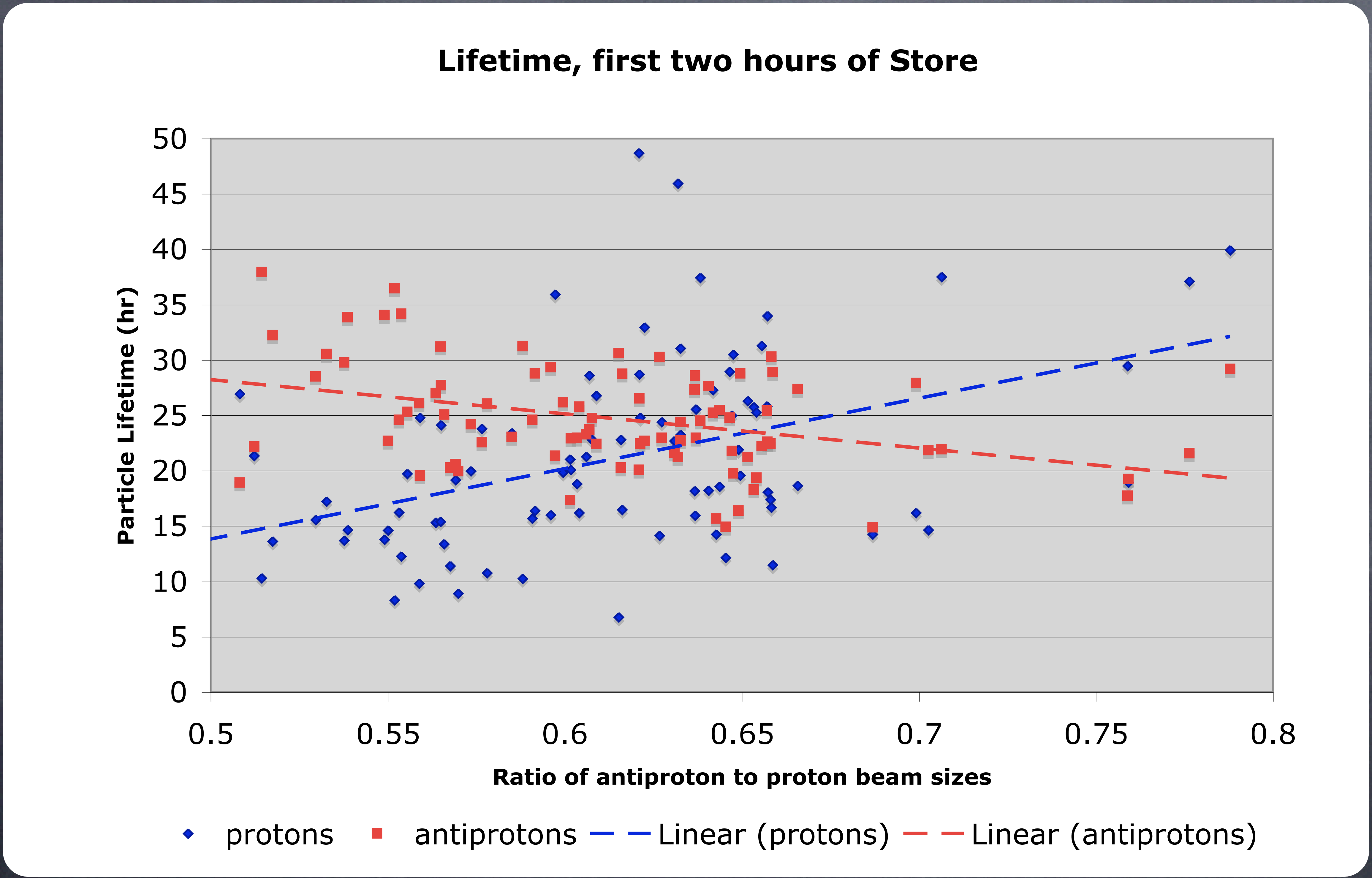
Recent history ...

- Recycler works hard to produce small emittance beams (3D)
- As Recycler delivers more intense, smaller antiproton bunches, often see degradation of proton beam lifetime
- Traditionally, considered Tevatron operation as ``weak" antiproton bunches in presence of ``strong" proton bunches
- Acting as a lens, the strength of the beam-beam interaction of pbars on protons now can be essentially the same as for protons on pbars
- However, the Tevatron beams do have different sizes, and the effects are nonlinear; this influences the tune spread of the two beams differently

Particle Lifetimes



~100 stores since last long shutdown

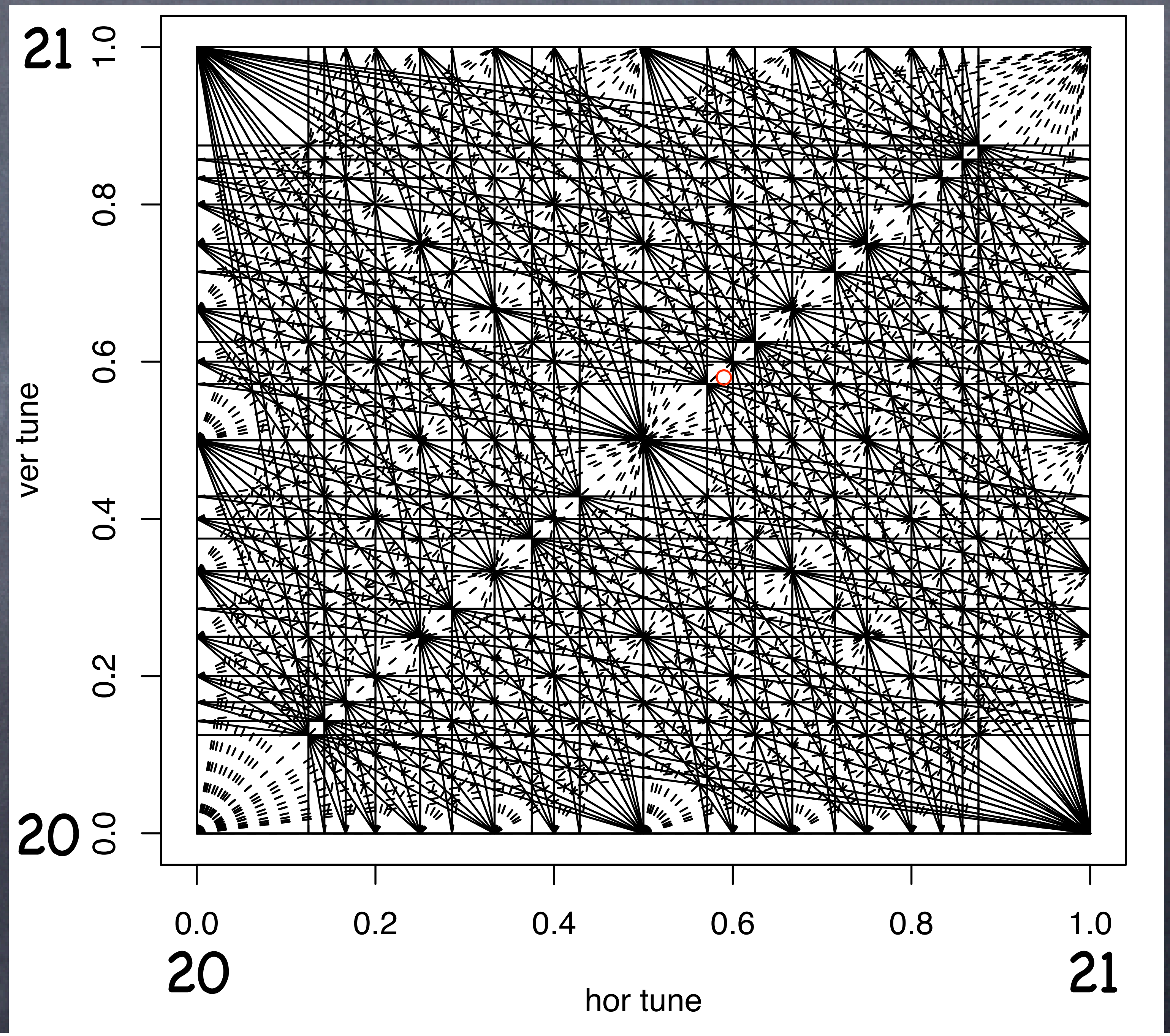
Earlier History ...

- In early Tevatron running (1980's) and in Sp$\bar{p}$S, found that intense proton beams affected the antiproton beam lifetime due to beam-beam interactions when total 'tune shift parameter' $\xi \sim 0.025$
  - The tune shift parameter given by: $\xi = \dfrac{3 r_o N}{2\epsilon}$
    - N = no. particles per bunch, ϵ = 95% norml. emittance, r_o = proton classical radius
  - note: 6x6 --> 12 "interactions" per turn, producing $\xi \sim 0.002$ per interaction
    - the reason for helical orbits

Tune Diagram

- Resonance Lines in tune space indicate potential problem spots for operation
- Tev working point:
  - ~ 20.59, 20.58

(through 8th order shown)



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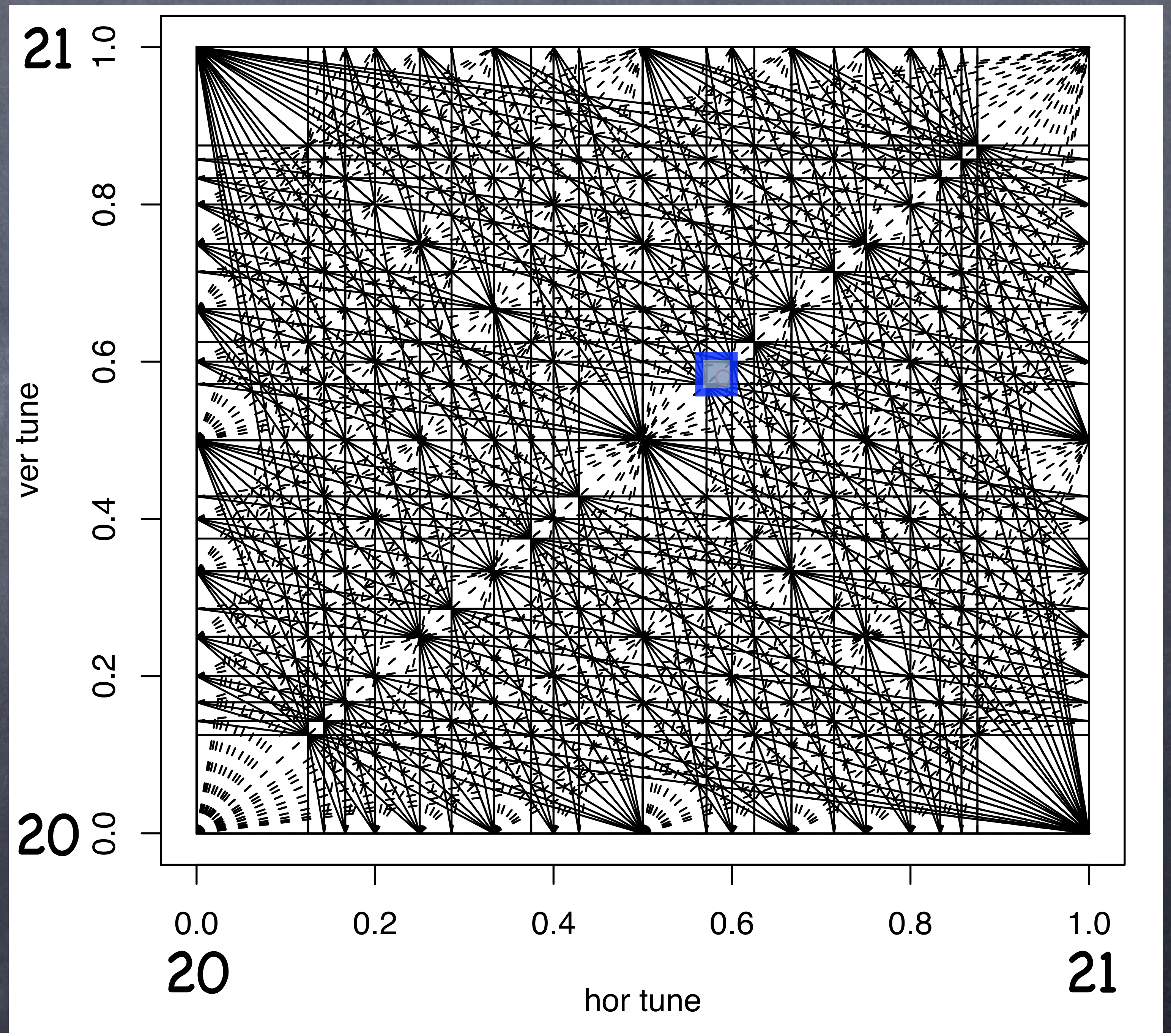

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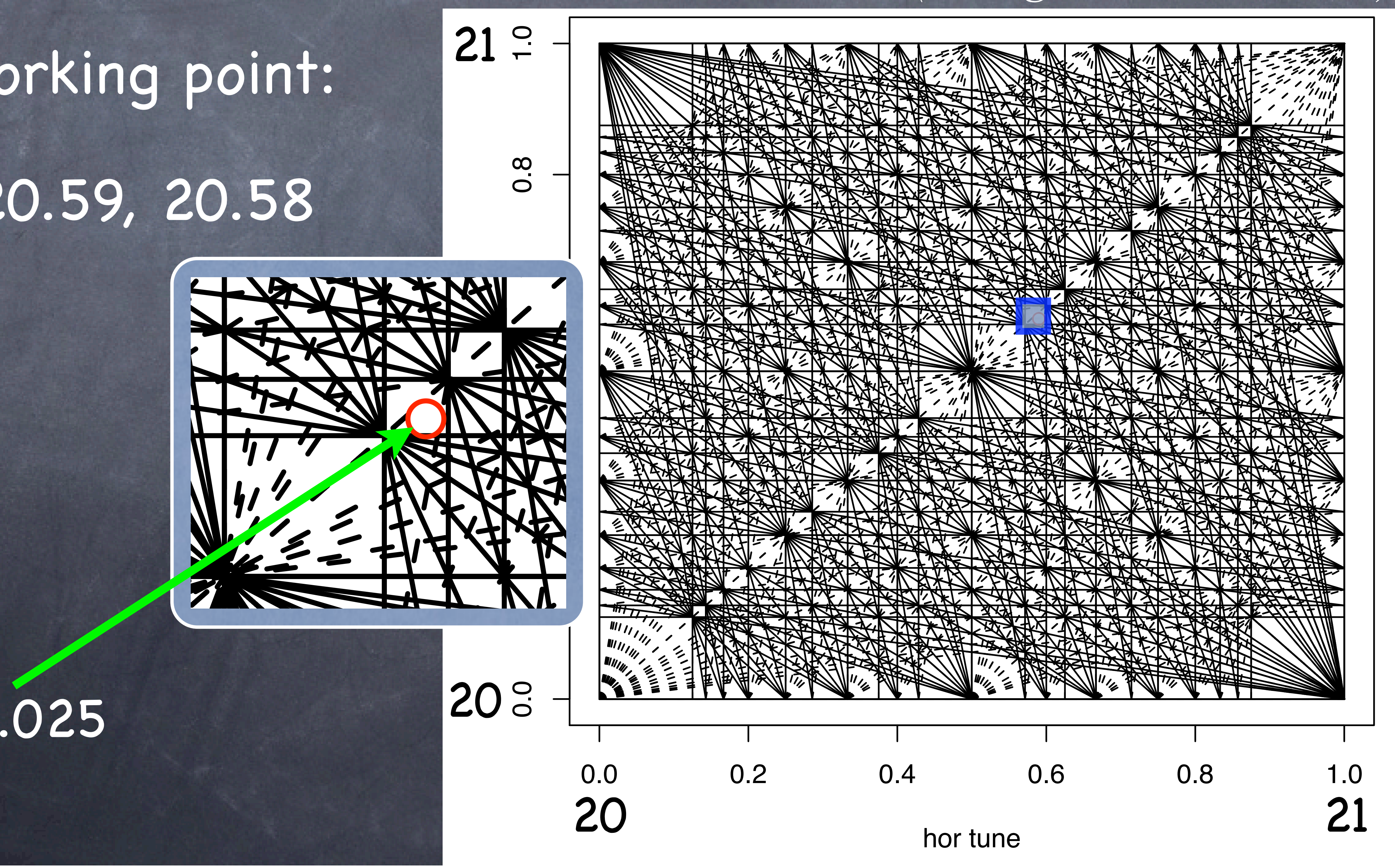
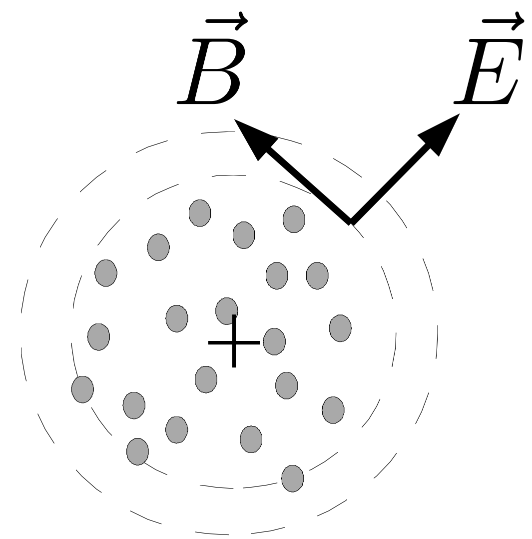
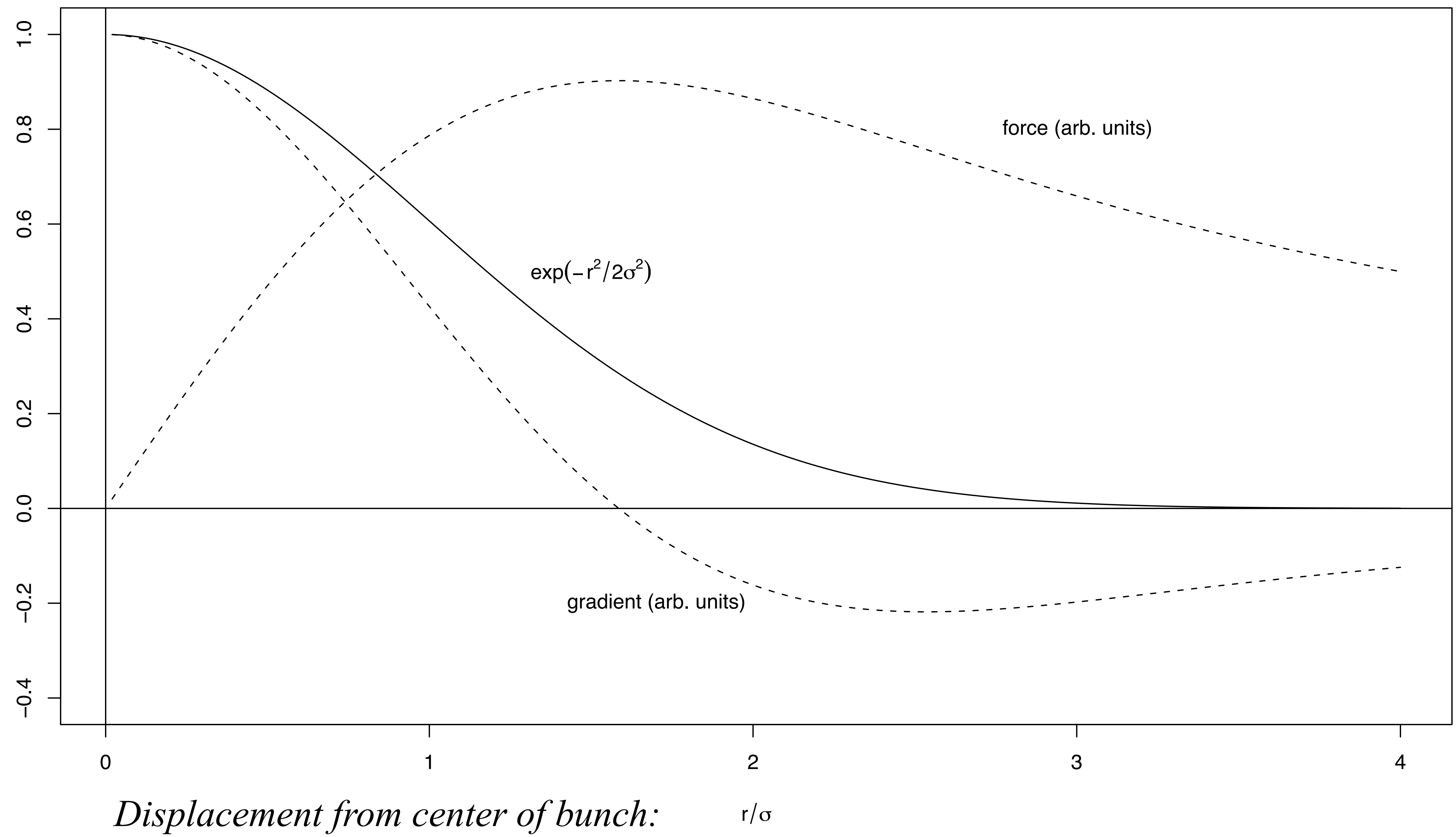


width ~ 0.025

The Beam-Beam Force

- Force, and its derivative (gradient), vary with position
- Gradients determine oscillation frequency …





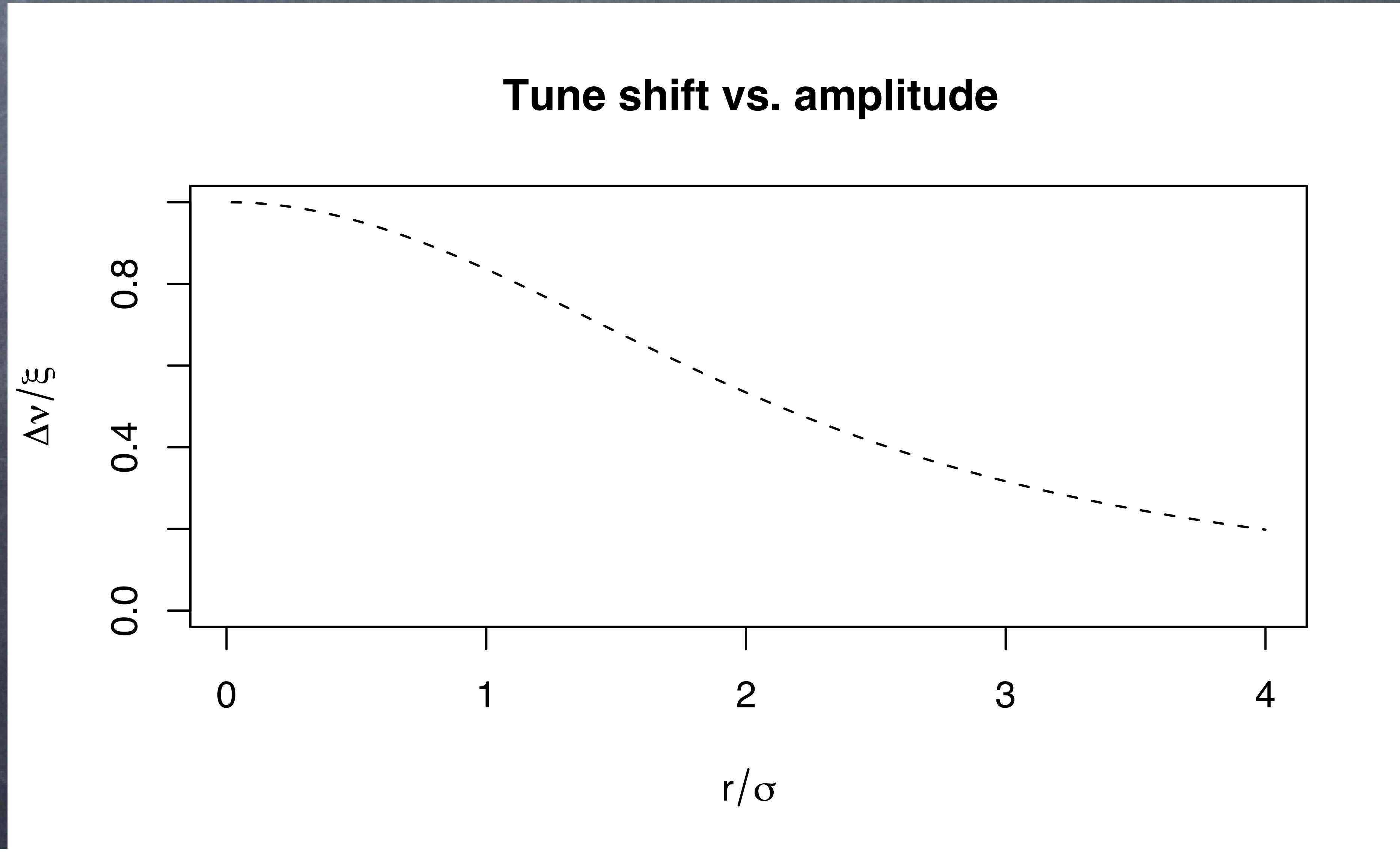
The Beam-Beam Tune "shift"

- Due to nonlinear nature of the perturbation, ``the tune" of a particle only has meaning in average sense,

small amplitudes, stay within center of other beam;
large amplitudes, most of time "outside" of other beam

$$\xi = \frac{3 r_o N}{2\epsilon}$$

If unequal transverse sizes, the two interacting beams will have unequal tune distributions



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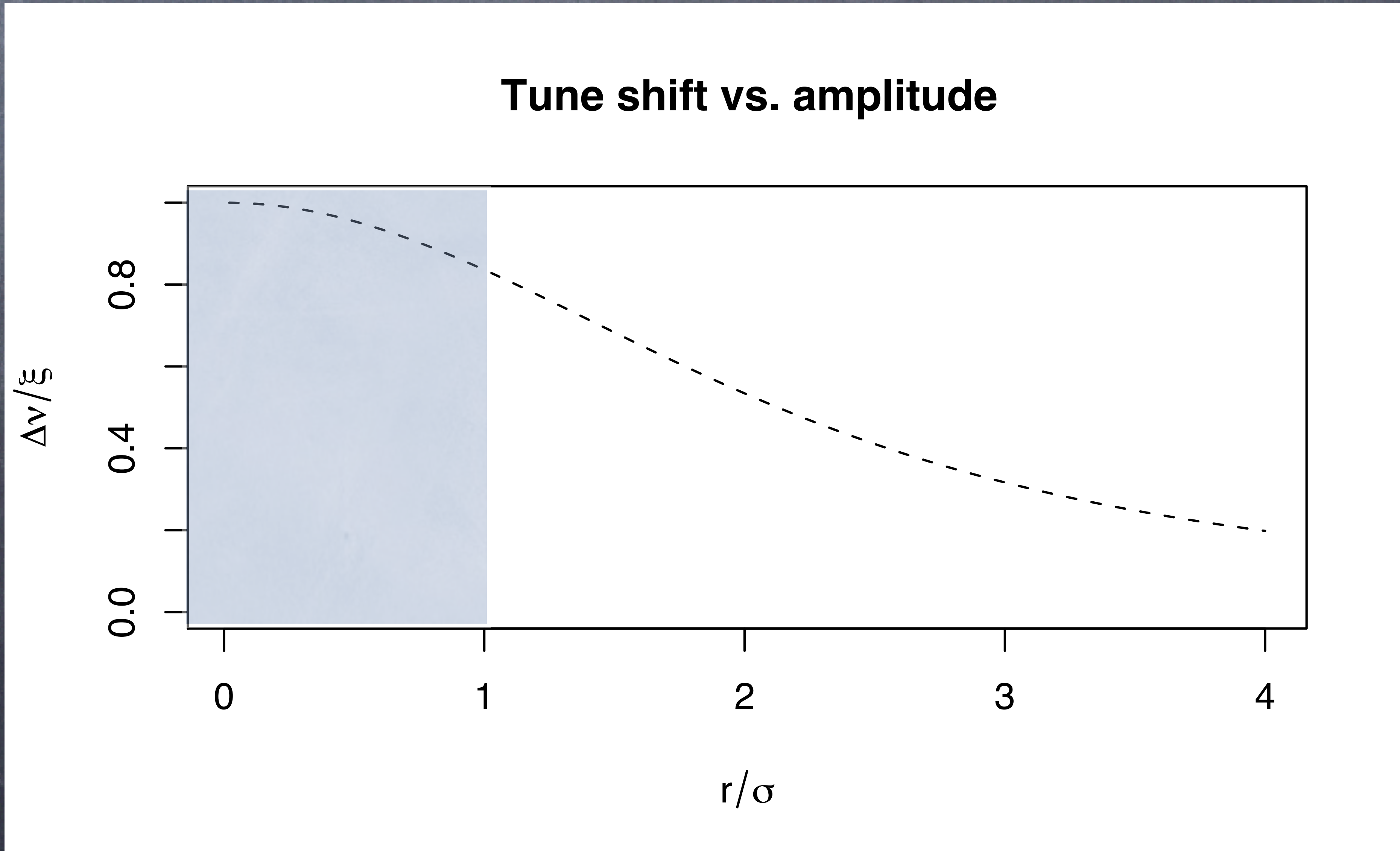

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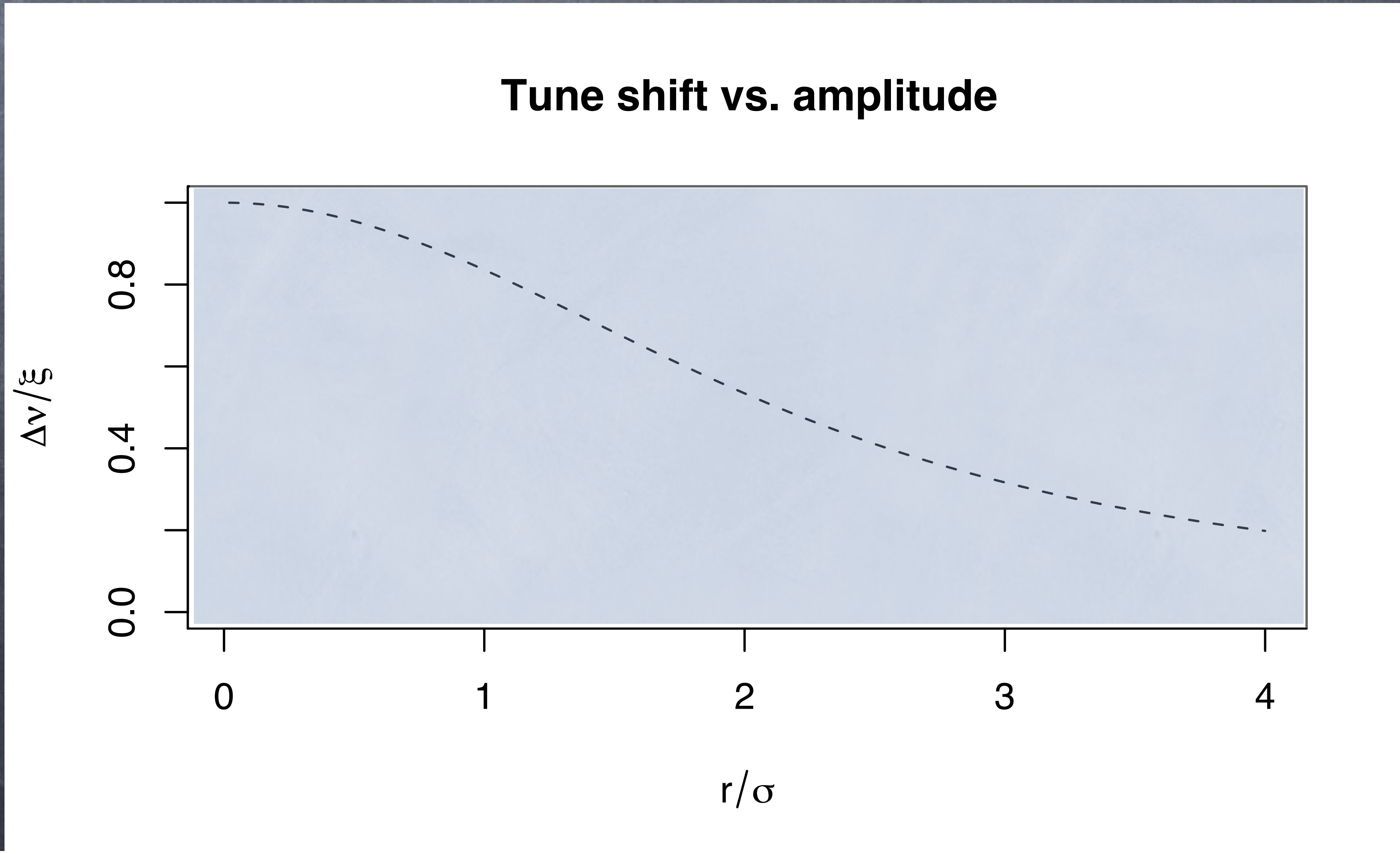


A Numerical Example

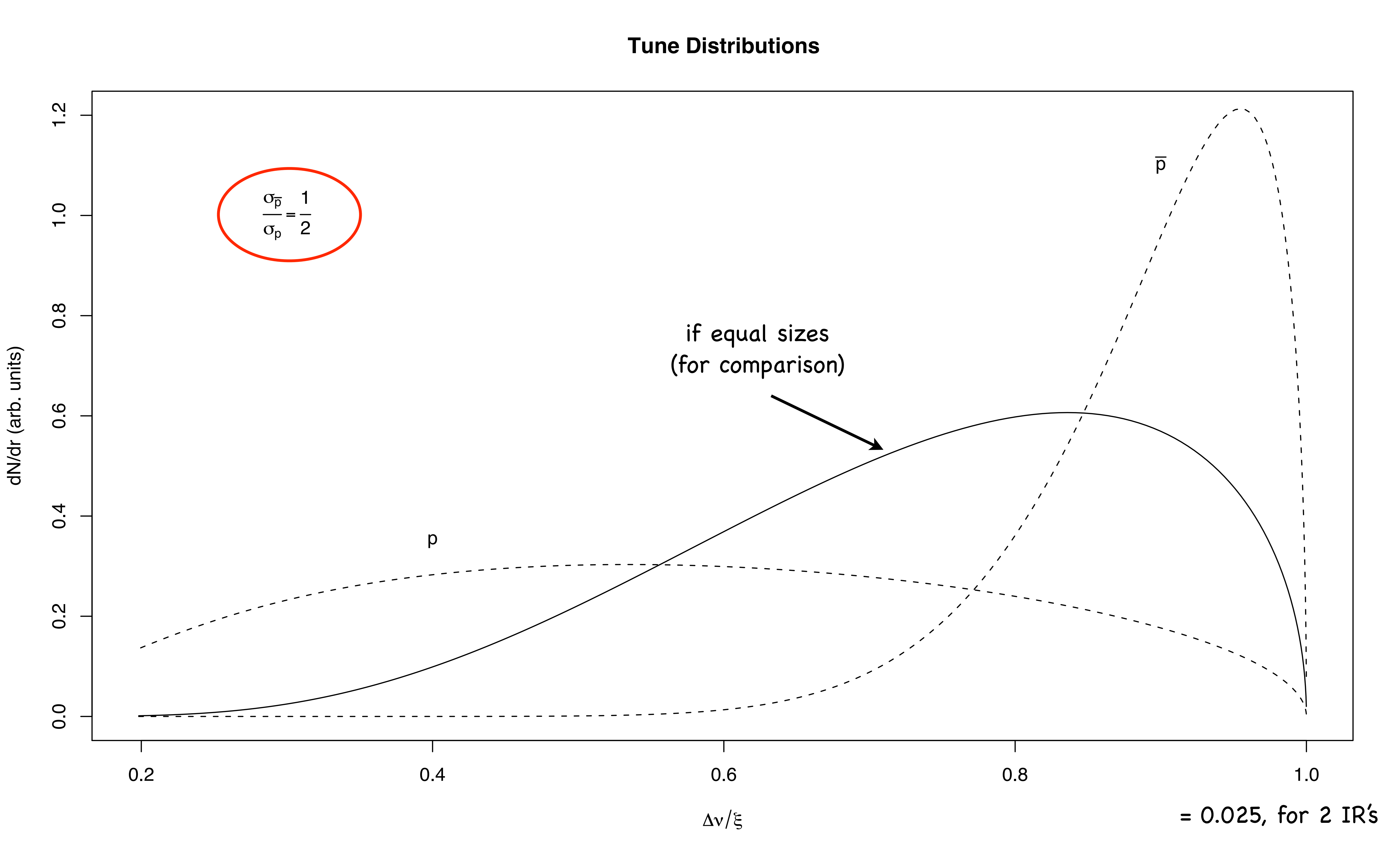
- Let's use: $$\xi = \frac{3(1.5 \times 10^{-18})(250 \times 10^{9})}{2 \cdot 14\pi\ 10^{-6}} = 0.0125$$ (due to p)

$$\bar{\xi} = \frac{3(1.5 \times 10^{-18})(70 \times 10^{9})}{2 \cdot 4\pi\ 10^{-6}} = 0.0125$$ (due to pbar)

Note:
2 IR's make total of 0.025

- But: $$\sigma_{\bar{p}}/\sigma_p = \sqrt{\frac{4}{14}} \approx \frac{1}{2}$$

Cold Pbars...


Tune Distributions
1.2
1.0
0.8
0.6
0.4
0.2
0.0
dN/dr (arb. units)
$\frac{\sigma_{\bar{p}}}{\sigma_p} = \frac{1}{2}$
$\bar{p}$
if equal sizes
(for comparison)
p
0.2
0.4
0.6
0.8
1.0
$\Delta\nu/\xi$
= 0.025, for 2 IR's

Now, increase Antiproton beam size...

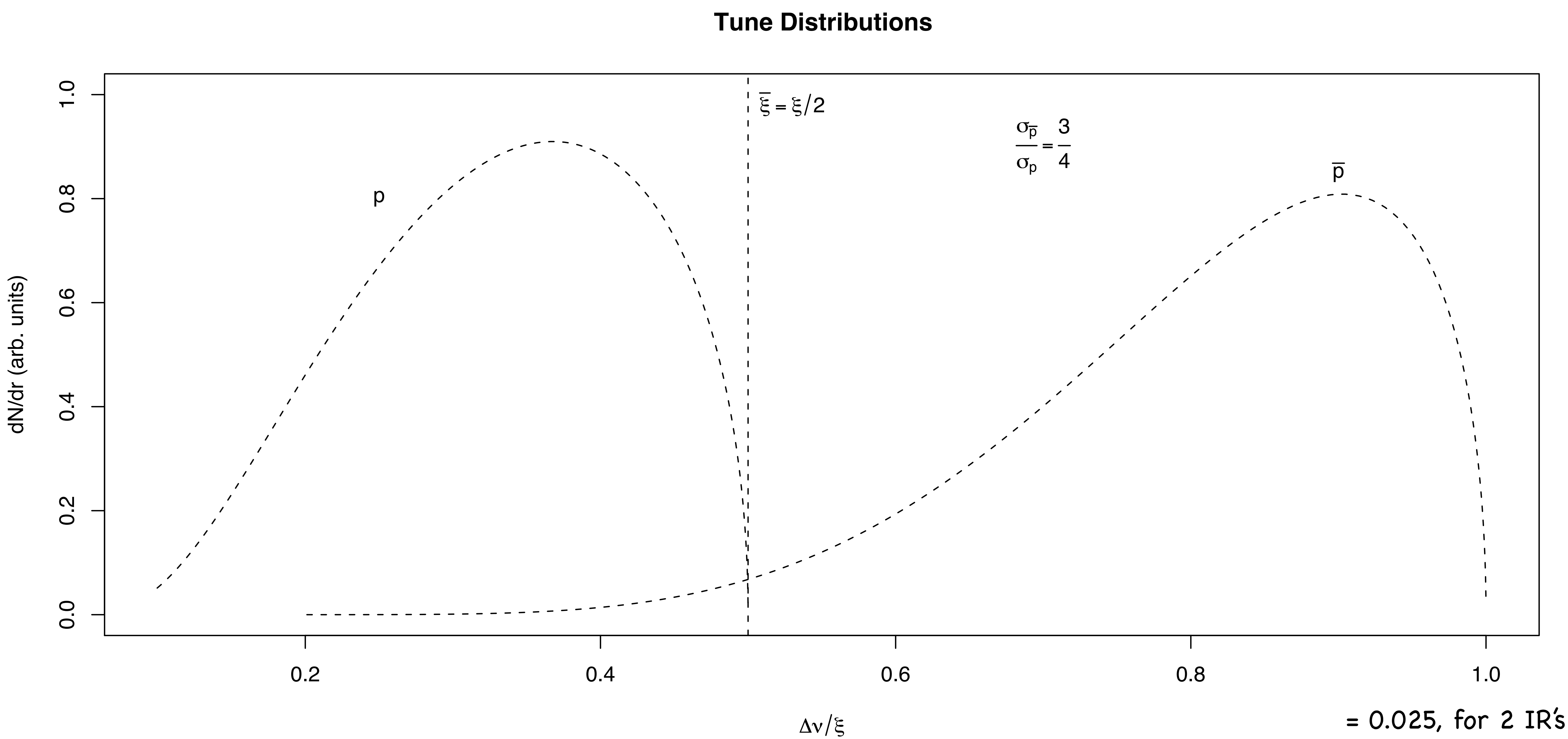
- Take above condition, and imagine doubling the antiproton emittance to 8π mm-mrad
- Results:

$$\bar{\xi} = \frac{3(1.5 \times 10^{-18})(70 \times 10^{9})}{2 \cdot 8\pi\ 10^{-6}} = 0.0062 = \xi/2$$

$$\sigma_{\bar{p}}/\sigma_p = \sqrt{\frac{8}{14}} \approx \frac{3}{4}$$

- Look at new tune distributions...

After the increase…



= 0.025, for 2 IR's

Now, roughly equal tune spreads in both beams

--> next, center these distributions appropriately

PBJ on Rye...

- Wish to manageably increase the antiproton beam size before initiate collisons
  - can (sometimes do) mismatch (mis-steer) at injection
  - however, keeping size small through injection/accel can be beneficial
- At high energy, use noise source on plates of pbar damper system to jostle the pbars transversely (PBJ) , increasing amplitudes of particle motion (emittance)
  - emittance increase prop. to time left on
- Needs calibration and a more automated implementation

Remarks

- No longer in weak-strong regime; must consider effects of pbars on the proton beam
- As push up pbar intensities and optimize integrated luminosity, need to "tailor" the beam sizes, intensities in order to land in reasonable regions of tune space
- Final adjustments to antiproton emittances can be beneficial at high energy; gaining experience with new technique using damper system (PBJ)
- Attempting to develop algorithm/recipe to make appropriate adjustments reproducible and reliable
- Reducing overall tune spreads may allow for higher proton bunch intensities as well

back up ...

Then and now...

$$\mathcal{L} = \frac{3 f_0 \gamma N (B\bar{N})}{\beta^* (\epsilon + \bar{\epsilon})} \cdot \mathcal{H}$$

- Late 1980's...

$$= \frac{3 \cdot 47,750 \cdot (800/0.938) \cdot (50 \times 10^9) \cdot (20 \times 10^{10})}{50 \cdot (2 \times 20\pi \times 10^{-4})} \cdot 0.6 = 10^{30}\ \mathrm{cm}^{-2}\mathrm{sec}^{-1}$$

$$\xi = \frac{3 \cdot 50 \times 10^9 \cdot (1.5 \times 10^{-16})}{2 \cdot 20\pi \times 10^{-4}} \approx 0.002$$

(x6 x 2 --> 0.024)

- Today...

$$= \frac{3 \cdot 47,750 \cdot (980/0.938) \cdot (300 \times 10^9) \cdot (250 \times 10^{10})}{30 \cdot ((20+4)\pi \times 10^{-4})} \cdot 0.6 = 300 \times 10^{30}\ \mathrm{cm}^{-2}\mathrm{sec}^{-1}$$

$$\xi = \frac{3 \cdot 300 \times 10^9 \cdot (1.5 \times 10^{-16})}{2 \cdot 20\pi \times 10^{-4}} \approx 0.012$$

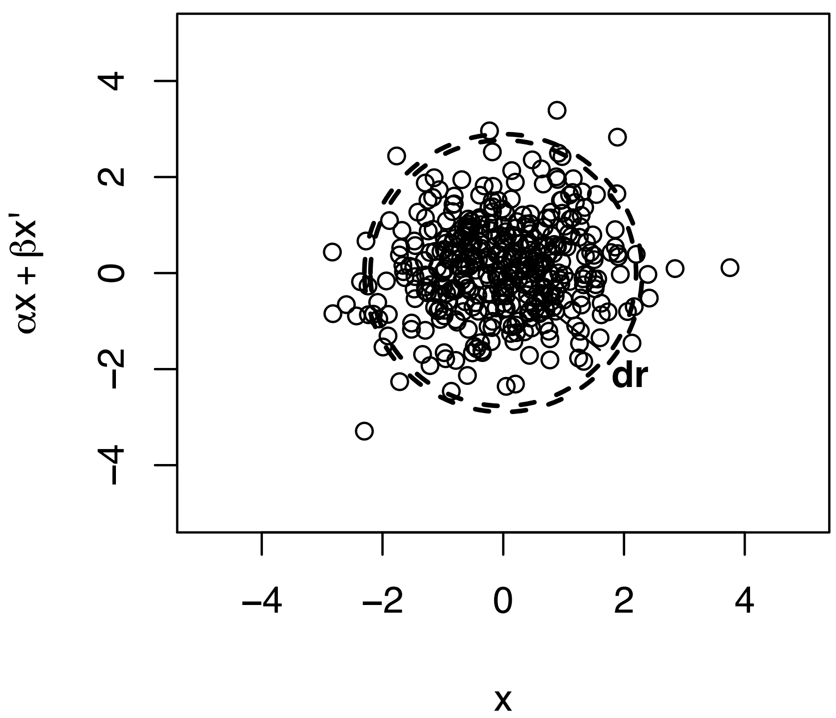
(x2 --> 0.024)

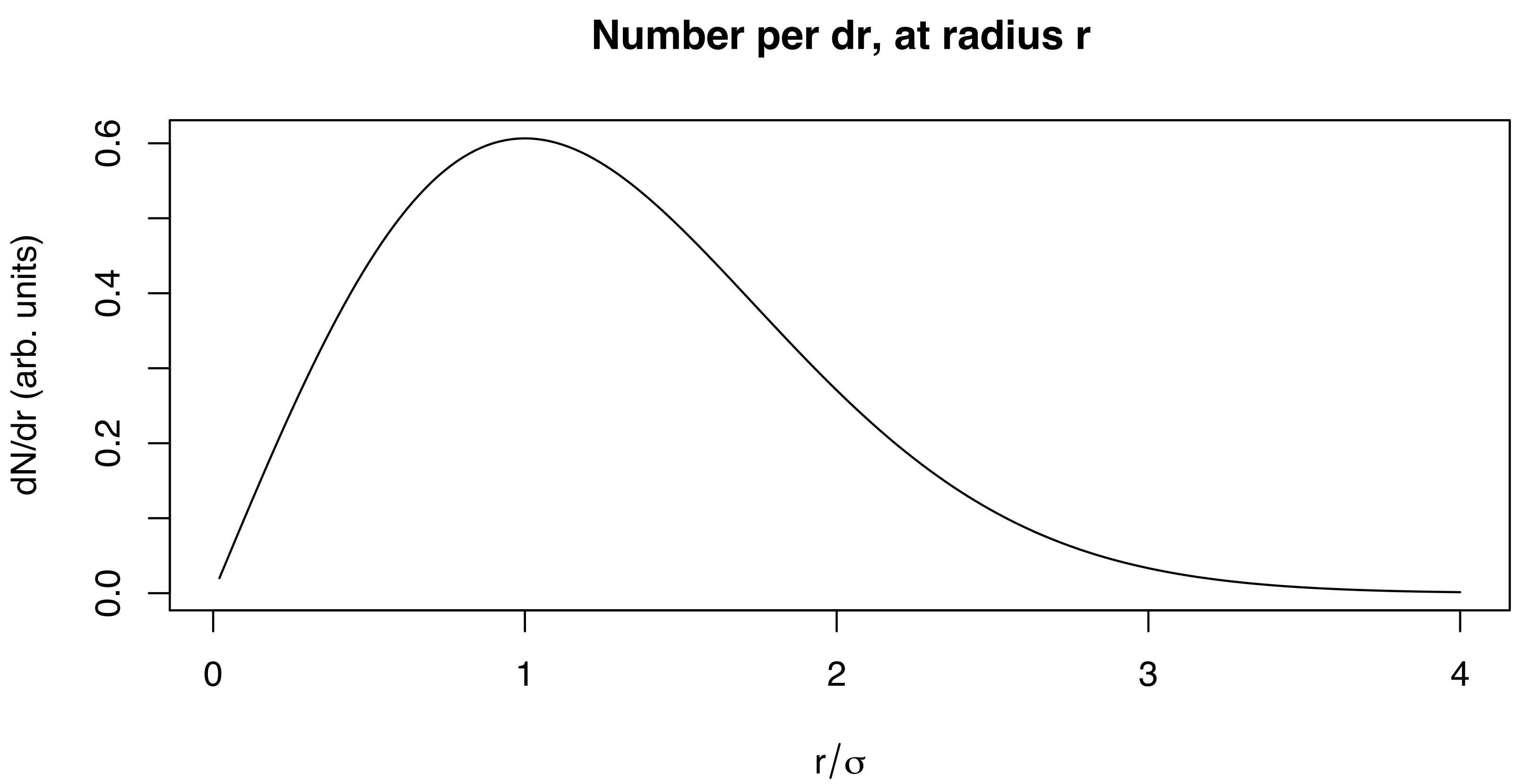
Estimating the Tune Spread due to Head-On Collisions

- Assume tune varies only with phase space amplitude, as given on previous slide
- Since each amplitude has a corresponding "tune," look at how many particles exist at each amplitude and plot no. particles vs. tune

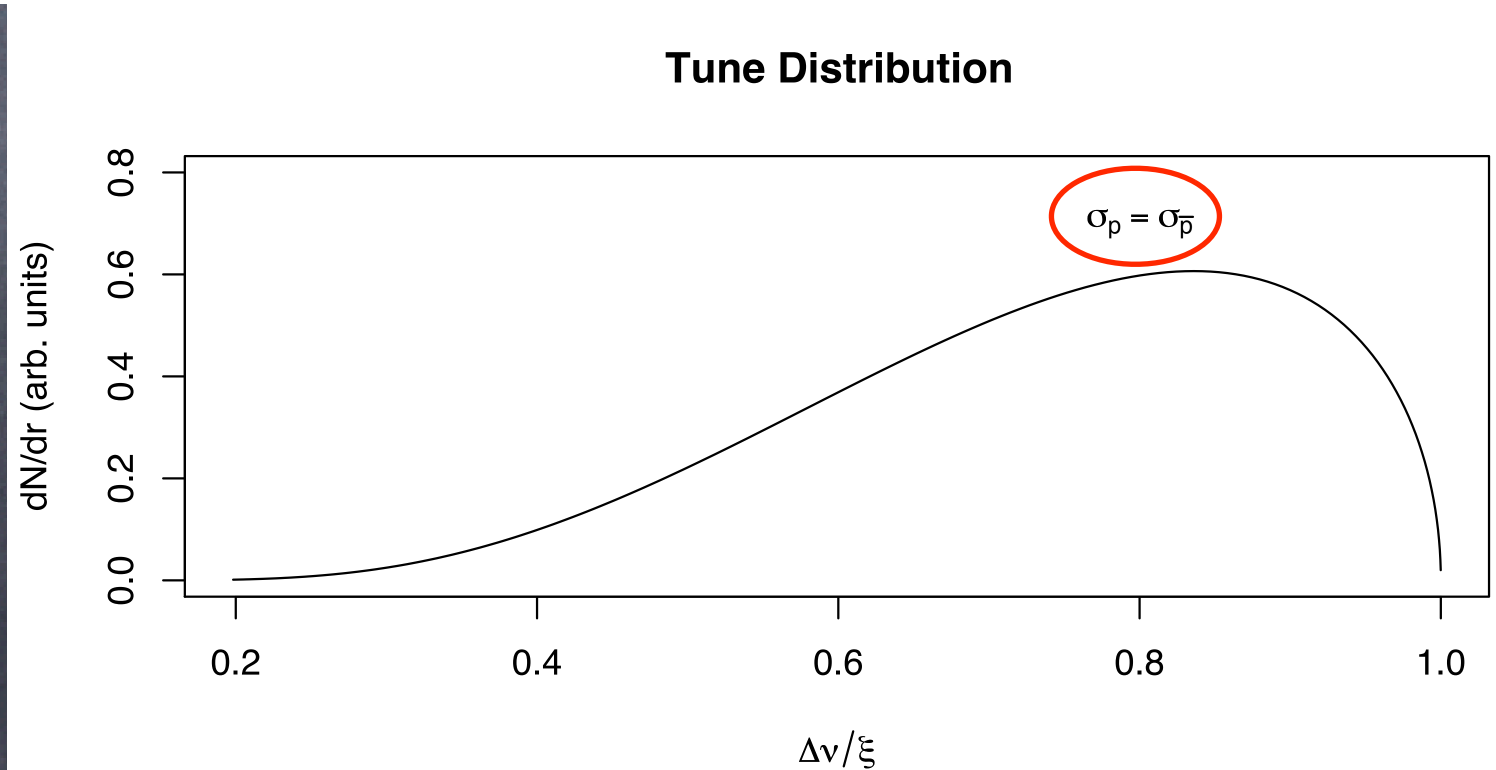
$$dN = \frac{N}{2\pi\sigma^2} e^{-r^2/2\sigma^2}\ r\,dr d\theta$$

Tune Distribution





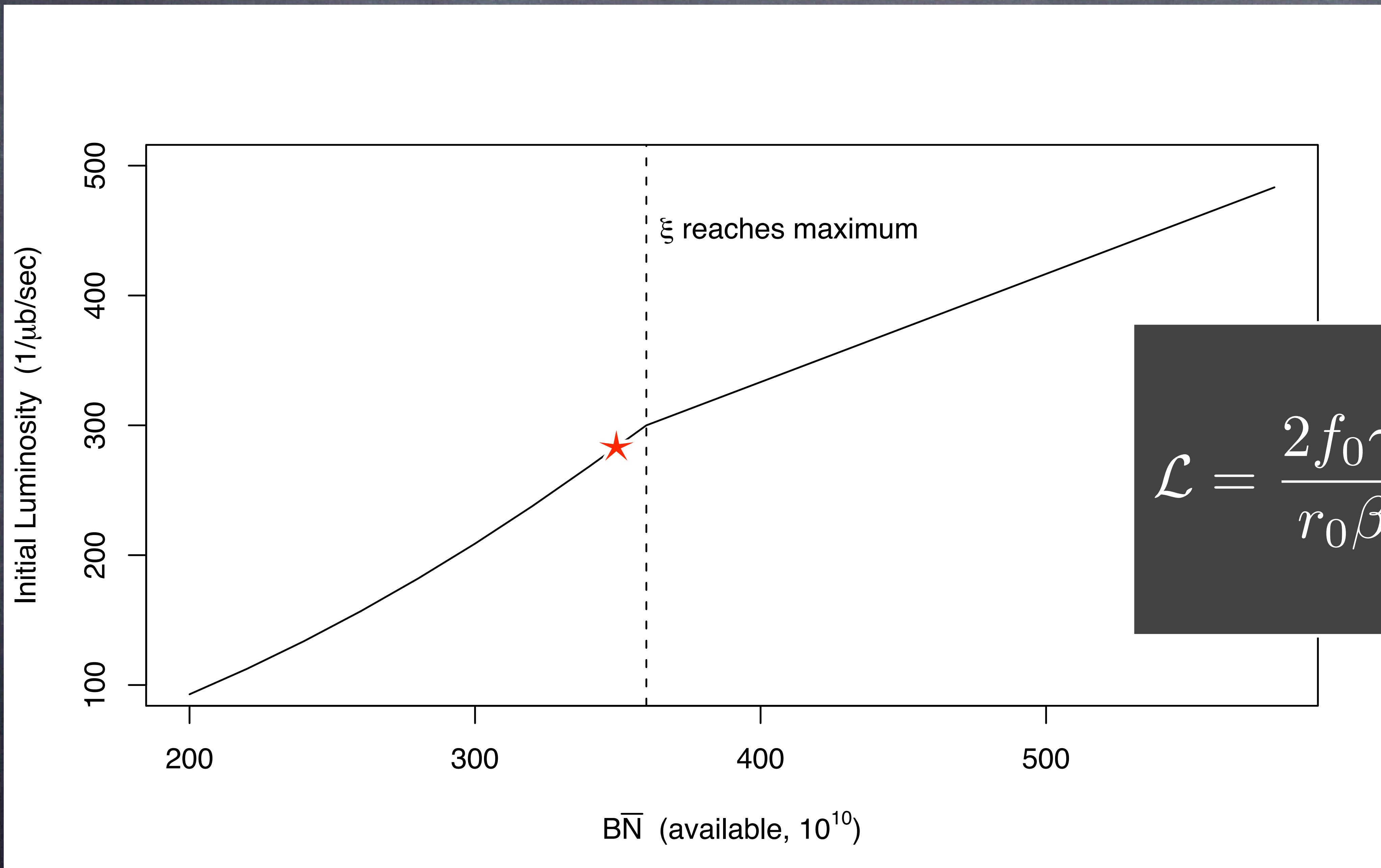
No. of particles per dr at radius r, and thus with tune ν:



Example Recipe...

- Suppose we like the conditions of previous slide...
- Given no. of pbars available for a shot, determine no. of protons to use and their emittance to keep $\bar{\xi} = \xi/2$ and tailor pbars accordingly to keep $\sigma_{\bar{p}}/\sigma_p \approx 3/4$
  - Ex: $N = \frac{7}{2}\bar{N};\;\; \epsilon = (3r_o/2\xi)\cdot N;\;\; \bar{\epsilon} = \frac{4}{7}\epsilon$
- Run proton beam at beam-beam limit; if its emittance is already too large, leave as is
  - i.e., make $\xi \le 0.012$

Initial Luminosity vs. Stash Size



Example only

$$\mathcal{L} = \frac{2f_0\gamma\xi}{r_0\beta^*} \cdot \frac{B\bar{N}}{1+\bar{\epsilon}/\epsilon} \cdot \mathcal{H}$$

- Assumes 80% make it to collisions, and that the conditions above "optimize" the luminosity lifetime